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USSR MOLYBDENUM RESOURCES, PRODUCTION

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The chief molybdenum mineral is molybdenite, MoS_2, from which 99% of all commercial molybdenum is obtained. The oxygen compounds of molybdenum, such as wolfenite $PbMoO_4$: powellite, $CaMoO_4$: and molybdite, $Fe_2O_3 \cdot 3MoO_3 \cdot 7^1/2HO_2$ are industrially insignificant.

Molybdenum ores and deposits of the USSR may be divided into four types, brief characteristics of which are given below.

1. Quartz-molybdenum ores are the most abundant, simple, and rich type. They are mostly monometallic and usually contain a certain amount of pyrite FeS_2. Multimetalic ores of this type include noticeable admixtures of copper, lead, and zinc in the form of chalcopyrite, gray copper ores, galenite, and sphalerite, as occurs at the Shakhtominskoye deposit. These admixtures are insignificant, but still have considerable effect on the process of molybdenite flotation. In spite of the stability of molybdenite in the majority of deposits and the limited zone of oxidation, in some cases the oxidation is developed sharply and to a considerable depth, as at the Sorskoye deposit. Oxide ores are essentially composed of powellite, molybdite, and molybdenum-containing limonite. The following deposits yield quartz-molybdenum ores: Umal'tinskoye, Chikoyskoye, Chindagatuyskoye.

2. Molybdenum-wolfram ores, by conditions of occurrence, are similar to proper molybdenum ores except for greater diversity of their mineralogical composition. Wolframite, $FeWO_4$, acquires the nature of an essential industrial component. Pyrite is one of the prevalent ore minerals. This type of ore occurs in quartz lodes as well as in accompanying greisens and represents gradual transition to proper wolfram ores. The Kok-kul'skoye and Akchatauskoye deposits produce ores of this type.

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3. Skarn ores, developed along contacts of igneous and sedimentary rocks, mostly limestones, are impregnated with molybdenite, which is frequently accompanied by scheelite, $CaWO_4$. Oxide ores of this type are characterized by the presence of powellite, substituting to a varied extent for molybdenite. Ores of this type are produced by the Tyrnyauzskoye, Lyangarskoye, and other deposits.

4. Copper-molybdenum ores are mostly stockwork-impregnated ores in various igneous rocks. They are penetrated by a dense network of thin veinlets. Molybdenite occurs in these veinlets as well as in the rocks themselves. Quartz copper-molybdenum veins of various thickness belong to this group. Oxide ores are characterized by the presence of secondary minerals, mainly molybdite and, to a lesser extent, powellite. The Kadzh[illegible]nskoye and Agarakskoye deposits produce ores of this type.

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In addition to extraction of molybdenum from the four types of ores here described, side recovery of this metal in the USSR takes place out of porphyritic copper ores.

Small concentration of molybdenum has been established in ores of some multimetallic deposits, for example, Aktyuz.

Molybdenite is present as a significant admixture in gold-bearing quartz-tourmaline veins of the Pil'noye deposit.

Molybdenum is used in the form of ferromolybdenum calcium molybdate, ammonium molybdate, and metallic molybdenum.

GOST E2415-43 for ferromolybdenum specifies, depending on carbon content, two grades. carbonless ferromolybdenum Mol with 50-65% Mo, 0.1% C, 0.5% Si, 0.1% As, 0.1% S, and 0.1% P, and low-carbon ferromolybdenum Mo2 with 50-65% Mo, 0.3% C, 2.0% Si, 0.2% S, 0.1% As, and 0.20% P.

Ferromolybdenum is smelted out of roasted concentrate containing molybdenum in the form of molybdic oxide MoO_3. Oxidizing roasting of molybdenite is done at 600°C and accompanied by elimination of sulfur and partial elimination of arsenic. The MoS_2 content in initial concentrate is desirable at its maximum, since admixtures complicate the process by increasing the amount of slags. The content of silica must be minimum; otherwise the excess of silica in the concentrate requires an additional amount of fluxes. This increases losses of molybdenum in slag. Due to these factors the requirements on the concentrate are very strict in respect to molybdenum and impurities.

Calcium molybdate may be obtained out of molybdenite as well as from wulfenite- and powellite-containing concentrates and ores. The technology for obtaining it consists of two stages of molybdenite roasting:

1. Oxidizing roasting of concentrate for sulfur elimination: $2MoS_2 + 7O_2 = 2MoO_3 + 4SO_2$.

2. Final roasting of oxidized concentrate in the presence of lime: $MoO_3 + CaO = CaMoO_4$.

Technical calcium molybdate represents a mechanical mixture of pulverized calcium molybdate, calcium oxide and calcium carbonate. The specific gravity of calcium molybdate is 4.25. There are two grades of calcium molybdate as follows:

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Chemical Composition in Percent

Grade	Minimum: Calcium Molibdate $CaMoO_4$	Minimum: Molybdenum	Maximum: S	Maximum: AS	Maximum: P
MK1	75	36.0	0.20	0.15	0.15
MK2	70	33.6	0.25	0.20	0.20

Limitation of sulfur, arsenic, and phosphorus is due to their harmful effect on the quality of metal.

Ammonium molybdate is obtained from molybdenite concentrate which is preliminarily roasted at 600° for converting to molybdic anhydride with simultaneous removal of sulfur in the form of sulfur dioxide and treated with ammonia, which dissolves the molybdic oxide as ammonium molybdate; the latter is filtered out, and its impurities, mainly copper, but some iron, are removed with the aid of ammonium sulfide or chloride. After treatment with lead nitrate to remove the excess of aluminum sulfide, the solution is evaporated.

The technology requires a highly rich concentrate to achieve the most complete lixiviation of molybdenum in the form of ammonium molybdate and to decrease the possibility of retaining molybdenum in tailings due to adsorption or formation of some compounds difficult for decomposition by ammonia.

Ammonium molybdate is the initial product for obtaining pure MoO_3 which, upon reduction, yields molybdenum used in the manufacture of wire, plates, and strips for electric bulbs and radio tubes.

The purity of ammonium molybdate is specified by GOST 2677-44 as follows:

	Grade I	Grade II
Sesquioxides, $Fe_2O_3 + Al_2O_3$, max	0.03	0.03
In this total Fe_2O_3, max	0.01	Not specified
Nickel, max	0.005	0.005
Manganese, max	0.01	0.01
Arsenic, max	0.005	0.005
Phosphorus, max	0.002	0.002
Sulfur, max	0.05	0.05
Residue after hydrochlorination, max	0.15	0.15
Including:		
Silica, max	0.03	Not specified
Alkali earth metals CaO + MgO, max	0.008	0.02
Alkali metals, in conversion to NaCl, max	0.1	Not specified.

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Metallic molybdenum is usually prepared by reducing molybdic oxide with hydrogen in special tube furnaces at 800-900°. This method is most usable and perfect, giving the purest metal, 99,95% Mo. There is also a method for reducing MoO_3 with metallic calcium.

The method of preparing molybdenum by thermal processing of MoO_3 with aluminum gives a product free of carbon but containing 1-2% Fe and a small amount of SiO_2.

The composition of molybdenum concentrates is determined in the USSR by GOST 212-41 as is given in the following table:

Admixtures (% max)

Grades	Molybdenum (% Min)	Phosphorus	Arsenic	Copper	Silica, SiO_2	Tin	Moisture	Typical Use
KM1	50	0.07	0.07	0.5	5.0	0.07	4.0	For ferromolybdenum Mo 1
KM2	48	0.07	0.07	1.0	5.0	0.07	4.0	--
KM3	47	0.15	0.07	2.0	7.0	0.07	4.0	For ferromolybdenum Mo 2 and calcium molybdate

The basic method for concentration of molybdenum ores is flotation, despite the fact that it does not give equally good results for all molybdenum minerals. Ores may be arranged in five groups by difficulty of concentration.

1. Quartz-molybdenum ores represent the basic source of molybdenum and are better adaptable to flotation than any other ores, since the molybdenite of these ores is easily submitted to the process of flotation with the aid of ordinary frothing agents. Joint application of frothers and collectors gives good results. Investigations of Soviet scientists corroborated successful results of using hydrocarbon oils in the flotation of these ores.

2. Copper-molybdenum ores present certain difficulties in concentration but are sufficiently well studied in laboratories and in practice. Basic flotation gives only a rough concentrate which is subjected to several cleaning flotations producing a collective molybdenum-copper concentrate. The latter may be separated by one of the following methods:

Method of cyanides, developed by B. I. Rozov and V. N. Soltanov, in which potassium and sodium cyanides are used for depression of copper minerals.

Sodium sulfide method developed by N. G. Gomelauri and K. G. Vartanyants.

Method of iron salts worked out by B. I. Rozov and G. A. Myasnikova. Application of iron salts is based on the capacity of $FeCl_3$ and $Fe_2(SO_4)_3$ to dissolve chalcopyrite without reaction with molybdenite.

3. Molybdenum-wolframite ores present no considerable difficulties in concentration. Molybdenum separation is done by flotation while wolframite is subjected to wet methods of concentration.

4. Skarn molybdenum-scheelite ores represent a more complicated problem for concentration. The method has to be selected in respect to the coarseness of scheelite. Coarse dispersion permits wet concentration in jigs and on tables. In cases of fine dispersion, the method of flotation is used for separation of molybdenite with subsequent separation of scheelite from tailings.

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5. Ores, containing oxidized molybdenum minerals, represent the greatest difficulties for concentration. Although powellite is easily adaptable to flotation with the application of fatty acids in the process, there still is no definitely established technology for the separation of molybdite and molybdenum combined with limonite. Despite the considerable complexity of concentration of oxidized molybdenum minerals, their flotation is beginning to develop in the USSR on an industrial scale.

Under conditions of the latest technique of concentration, both sulfide and oxide molybdenum ores have commercial significance. Therefore, new deposits are studied, with disregard for the form in which the molybdenum is present, mainly considering only a minimum metal content. The latter varies over a wide range depending on the type of ore. In complex ores, permitting side recovery of molybdenum, a content expressed in thousandths of one percent may even be considered for extraction.

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Total resources of molybdenum in the USSR are sufficient to meet the requirements for this metal for a number of decades. However, a steady increase in its consumption by the growing ferrous metallurgical industry demands further development of supply sources.

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